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**(12) United States Patent**  
**Li et al.****(10) Patent No.: US 7,273,095 B2**  
**(45) Date of Patent: Sep. 25, 2007****(54) NANOENGINEERED THERMAL MATERIALS BASED ON CARBON NANOTUBE ARRAY COMPOSITES**6,231,744 B1 5/2001 Ying et al.  
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**(\*) Notice:** Subject to any disclaimer, the term of this patent is extended or adjusted under 35 U.S.C. 154(b) by 0 days.

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**(21) Appl. No.: 10/825,795**Banerjee, Kaustav, et al., "3-D Heterogeneous ICs: A Technology for the Next Decade and Beyond", *3th IEEE Workshop on Signal Propagation on Interconnects*, Venice, Italy, May 13-16, 2001.**(22) Filed: Apr. 13, 2004**

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US 2007/0163769 A9 Jul. 19, 2007**Primary Examiner**—Teresa J. Walberg**(74) Attorney, Agent, or Firm**—John F. Schipper; Robert M. Padilla**(51) Int. Cl.**  
**F28F 13/00** (2006.01)**(57) ABSTRACT****(52) U.S. Cl.** ..... 165/185; 165/80.3**(58) Field of Classification Search** ..... 165/185,  
165/80.3; 361/704

See application file for complete search history.

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A method for providing for thermal conduction using an array of carbon nanotubes (CNTs). An array of vertically oriented CNTs is grown on a substrate having high thermal conductivity, and interstitial regions between adjacent CNTs in the array are partly or wholly filled with a filler material having a high thermal conductivity so that at least one end of each CNT is exposed. The exposed end of each CNT is pressed against a surface of an object from which heat is to be removed. The CNT-filler composite adjacent to the substrate provides improved mechanical strength to anchor CNTs in place and also serves as a heat spreader to improve diffusion of heat flux from the smaller volume (CNTs) to a larger heat sink.

**30 Claims, 7 Drawing Sheets**